Fourier Domain in the Analysis of Egyptian Textiles in Archeology

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Abstract—In Egyptian archaeological sites, fabrics frequently appear such as bandages of the mummies, whose study could provide significant information. The current analysis system relies on a visual count of the number of horizontal and vertical threads within a one-centimeter square. This work proposes applying the Fourier transform to perform this task. However, the application of this tool, as used in the analysis of textile supports in paintings, yields very poor results. The modifications proposed and developed here, based on exploiting diagonal periodic patterns observed in these ancient Egyptian textiles, provide an accurate estimation of vertical and horizontal thread counts throughout the fabric.

Index Terms—Frequency domain, Pattern recognition, Thread counting, Cultural heritage, Egyptian textiles.

I. Introduction

Textiles are frequently found in Egyptian archaeological sites, in most cases related to the clothing or the linen bandages used during the mummification process. The study of these textiles is of great interest to archaeologists and historians [1], [2]. Such studies allow for the determination of the fabric's quality, typically through the analysis of the material and thread density. In some cases, they can even support theories regarding the grouping and re-wrapping of mummies throughout history.

In the study of plain weave textiles, the most common type, the prevalent method involves a visual count of the number of horizontal and vertical threads within a one-centimeter grid [3], [4]. This procedure, besides being tedious, allows for thread counts at certain points of the canvas but does not provide a comprehensive count across the entire fabric. In this work, we propose a novel approach to automatically count the number of threads over the whole fabric. The main contributions of the proposal are as follows:

- To the best of our knowledge, this is the first instance of an automatic thread-counting approach being applied to Egyptian textiles from archaeological contexts.
- We conducted a frequency domain analysis of Egyptian textiles, revealing that horizontal or vertical periodic patterns are scarcely observable.
- We introduced a novel approach for thread counting that emphasizes diagonal periodic patterns, particularly in cases where primary horizontal or vertical frequencies are not discernible in the frequency domain.
- We successfully applied our method to two case studies, demonstrating its potential and effectiveness.

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II. Previous works

For over a decade, automatic counting techniques have been used for canvases in paintings, see [5]–[7] for further details. For case studies, you may consult [8] or [9], where paintings by Van Gogh or Vermeer are studied. Usually, automatic methods are based either on the frequency domain or machine learning. The latter, see e.g. [10], [11], have the drawback of requiring a preliminary step of labeling and training, as they are supervised discriminative methods. In contrast, frequency domain-based methods are immediate to use, do not require labeling, and offer very precise results across a wide range of fabrics. Besides, it is usually robust to the presence of noise, such as drawings, paintings, and artifacts. The frequency domain thread-counting algorithms usually resorts to the 2-dimensional discrete Fourier transform (2D-DFT) [6], [12], [13], although the power spectral density (PSD) is also exploited [14]. The 2D-DFT method is described in Fig. 1: a patch of the image is pre-processed, the

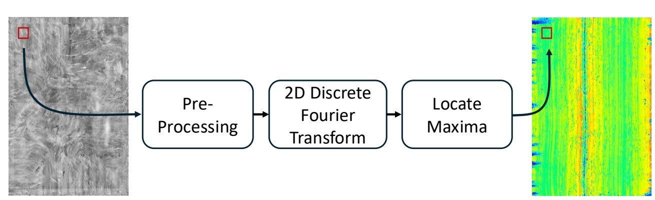


Fig. 1: Description of the method to compute the vertical thread density map with the FT. Examples of the outputs of the blocks are included below arrows.

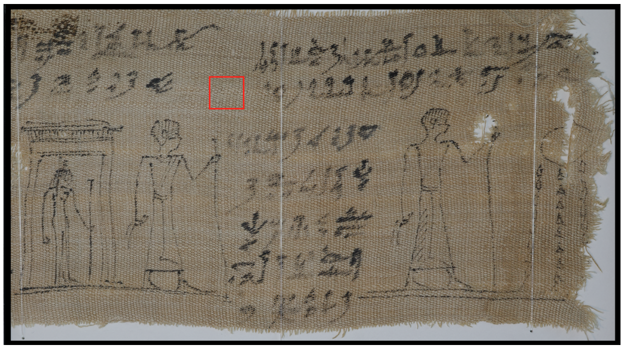


Fig. 2: Ancient Egyptian textile sample 1, with a red 1 cm side square of the area zoomed in 4.

2D-DFT is applied, maximum values are located in the horizontal axis to determine the vertical thread count, then the result is represented in an image where colors are mapped to density values. The process is repeated to locate the maximum in the vertical axis to estimate horizontal densities. These approaches usually use the scanned image of the X-ray of the canvas as input. However, a grayscale picture can also be used if the original fabric can be observed.

III. Ancient Egyptian Textiles

In this study, we have worked with two Egyptian textiles from the Museo Arqueológico Nacional (MAN) of Spain which we will cite as sample 1 (1984/79/IX/8: ca. 1069-332* B.C. Third Intermediate Period) shown in Fig. 2 and sample 2 (Anubis: ca. 399-331 B.C. Greco-Roman Period, MAN 16225) included in Fig. 3. A 1 cm side is marked in both figures in red and the inside is exhibited in Fig. 4.a and Fig. 4.b, for sample 1 and sample 2 respectively. The averaged 2D-DFT is applied throughout the fabric to obtain the PSD, depicted in contour lines in Fig. 6 for sample 1 and in Fig. 7 for sample 2. We find some main differences concerning the PSD found in canvases:

1) Maximum frequencies are beyond 25.
2) The peak value in the 2D-DFT corresponding to the horizontal or the vertical thread frequency is quite attenuated compared to the other one.
3) A large peak value is observed between the locations corresponding to the horizontal and vertical thread frequencies.

We have been working on thread counting in canvases for more than a decade, and it is quite uncommon to find plain weave fabrics of larger thread densities than 25 thr/cm. This conclusion is supported, e.g., by the analysis of French painting in [15] for the 17th-20th centuries and 44 painters whose densities were in the range 6-23.3 thr/cm. However, in the example in Fig. 2 the maximum for horizontal threads is close to 30. In Fig. 4.a we include a 1 cm side patch, the one marked in red in Fig. 2. It can be observed 10 vertical threads (you may count along the red dashed horizontal line Fig. 4.a), while it is not so easy to count the horizontal ones (along the vertical green dashed line in Fig. 4.a), around 24 threads. In the textile in Fig. 3, see Fig. 4.b, the densities for vertical threads are in the range $40 - 65$.

Second, maxima in the vertical or horizontal axis of the 2D-DFT should be observed for both the horizontal and vertical threads, respectively. However, in the PSD in Fig. 6 for the textile sample 1 in Fig. 2, the peak value that should be around ± 25 in the vertical axis is one order of magnitude below the peak found in the horizontal one, around 10. Regarding the textile sample 2 in Fig. 3, its PSD in Fig. 7 reveals the absence of a peak value around 50 in the horizontal axis. The application of 2D-DFT approaches used for fabrics of canvases is not available for these textiles. The approach will try to find any maximum along the axis, but since no peak is observed around the true frequency of the threads, it finds any other, usually at lower frequencies. In Fig. 5, we include the horizontal thread counting in every location computed by a standard 2D-DFT for sample 1, i.e., looking for the maximum in the vertical axis of the 2D-DFT. A noisy result can be observed, with many areas below 20, when they should be around 25.

Third, a high-value maximum is observed in both cases at the middle point between the locations where the peaks for the vertical and horizontal densities should be located. In Fig. 6 this peak can be found in the 4th quarter at, approximately, position $(5, -12)$. In Fig. 4.b we depict a solid blue line indicating the orientation revealed by this peak. In Fig. 7, this maximum is located approximately at $(23, 9)$.

IV. A new approach for Egyptian textiles

Given the previous analysis, it can be concluded that for the samples of ancient Egyptian textiles analyzed here, the off-the-shelf frequency domain approach cannot be used. At least to estimate the value of the larger thread density, either for the vertical or the horizontal threads. 2D-DFT methods are based on the finding of the peak values in the horizontal and vertical axes. However, as discussed above,

Fig. 3: Ancient Egyptian textile sample 2.

(a) (b)

Fig. 4: A 1 cm patch from Ancient Egyptian textile sample 1 in (a), and sample 2 in (b). In (a), we include dashed lines to indicate a vertical and a horizontal thread, while a diagonal pattern is highlighted in a solid blue line.

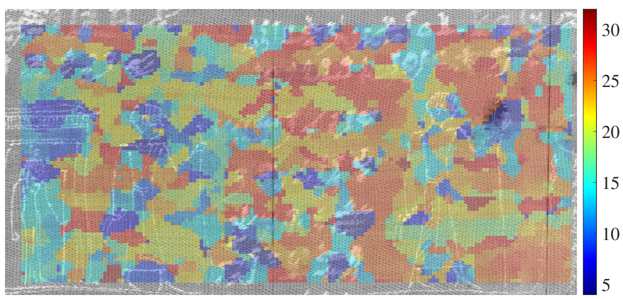


Fig. 5: Horizontal thread counting with standard 2D-DFT approach for textile in Fig. 2.

in one of these axes these peaks are either quite low or non-observable at all. Hence, noisy results are obtained. To circumvent this problem we propose a new approach. This novel method exploits diagonal patterns in the textile. We locate the maximum in the 2D-DFT corresponding to this diagonal pattern, generated by the crossing points between threads. Then estimate the location of the non-observable maximum with this information and the location of the observable one.

The algorithm first applies the standard approach for thread counting, briefly sketched in Alg. 1, where we

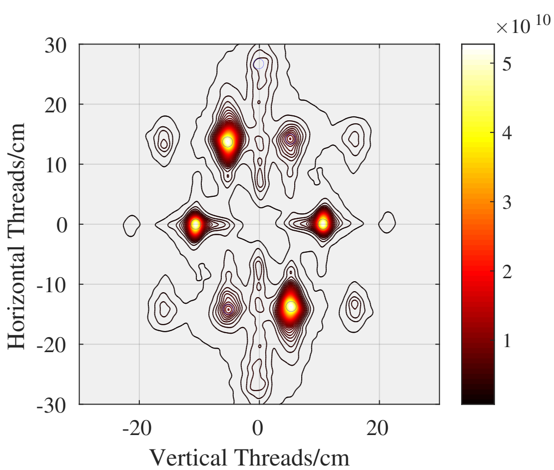


Fig. 6: PSD of the textile sample 1 in Fig. 2.

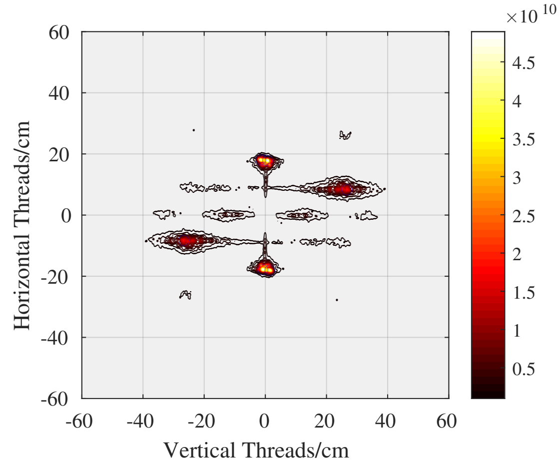


Fig. 7: PSD of the textile sample 2 in Fig. 3.

get the position and values of the peaks, m_h and m_v, found in the vertical and horizontal axis, respectively, after applying the 2D-DFT to a patch of the image at a given location within the textile. Note that the maximum in the horizontal axis leads to the frequency of the vertical threads, and the one found in the vertical one to the frequency of the horizontal ones.

Algorithm 1 Frequency Domain Thread Counting

1: Input: 2D-DFT of a patch of the image, ranges where to locate maxima.
2: Compute the absolute values, m_h, and its position, (x_h, y_h) of the maximum value in the specified vertical range.
3: Compute the absolute values, m_v, and its position, (x_v, y_v) of the maximum value in the specified horizontal range.
4: Return: m_v, m_h, (x_h, y_h), (x_v, y_v)

Then, we proceed by computing the maximum corresponding to the diagonal crossing-point patterns, observed in the first or fourth quadrant of the 2D-DFT as described in Alg. 2. In the algorithm, we need to set a couple of parameters to define the area in the 2D-DFT where to look for the maximum. In the experiments we used $\Delta_v = x_v/3$, $\Delta_h = x_h/3$ and $\Gamma = 0.75c_{max}$ where c_{max} is the maximum frequency value allowed.

Finally, we estimate the position of the missing peak with the lowest value using the positions of the observable maximum in the other axis and the maximum found in the quadrants. This procedure is described in Alg. 3, where with γ we control if we use the values (x_q, y_q).

V. Results

We applied the proposed novel approach to the two samples analyzed above.

Algorithm 2 Find maxima in the first or fourth quadrant

Input: 2D-DFT of patch of image, Δ_v, Γ_v, Δ_h, Γ_h
if $m_h > m_v$ then
    First quadrant: Compute the position, (x_{q1}, y_{q1}) of the maximum value, m_{q1}, in the area in the range $([x_v/2 - \Delta_v, x_v/2 + \Delta_v], [y_v - f_{min}, y_v + \Gamma_v])$
    Fourth quadrant: Compute the position, (x_{q4}, y_{q4}) of the maximum value, m_{q4}, in the area in the range $([-x_v/2 - \Delta_v, x_v/2 + \Delta_v], [y_v - f_{min}, y_v + \Gamma_v])$
else
    First quadrant: Compute the position, (x_{q1}, y_{q1}) of the maximum value, m_{q1}, in the area in the range $([x_h - f_{min}, x_h + \Gamma_h], [y_h/2 - \Delta_h, +y_h/2 + \Delta_h])$
    Fourth quadrant: Compute the position, (x_{q4}, y_{q4}) of the maximum value, m_{q4}, in the area in the range $([x_h - f_{min}, x_h + \Gamma_h], [-y_h/2 - \Delta_h, +y_h/2 + \Delta_h])$
end if
if $m_{q1} > m_{q4}$ then
    $(x_q, y_q) = (x_{q1}, y_{q1})$
else
    $(x_q, y_q) = (x_{q4}, y_{q4})$
end if
Return: m_q, (x_q, y_q)

A. Ancient Egyptian textile sample 1

In Fig. 8 we include the results for the horizontal thread counting of sample 1. Compared to the result in Fig. 5 horizontal patterns are observed, as expected, as we have the same threads along the horizontal direction. The histograms for both methods are depicted in Fig. 9: the new approach proposed in red, to the right, and the standard 2D-DFT in blue, to the left. The histogram values correspond to the number of occurrences found in the fabric by the algorithms for every count number. While the standard 2D-DFT approach is guessing the values in the range 4-30, our approach concentrates the values in the range 22-34, fitting the conclusions drawn from the observation of the PSD in Fig. 6 and the visual counting

Algorithm 3 Locate non/hardly observed peak in axis

Input: m_v, m_h, m_q, γ, (x_h, y_h), (x_v, y_v), (x_q, y_q)
if $m_h > m_v$ then
    if $m_v < \gamma m_q$ then
        $x_v = x_h - 2(x_h - x_q)$
        $y_v = y_h + 2(y_q - y_h)$
    end if
else
    if $m_h < \gamma m_q$ then
        $x_h = x_v + 2(x_q - x_v)$
        $y_h = y_v - 2(y_v - y_q)$
    end if
    Return: (x_v, x_y), (x_h, y_h)
end if

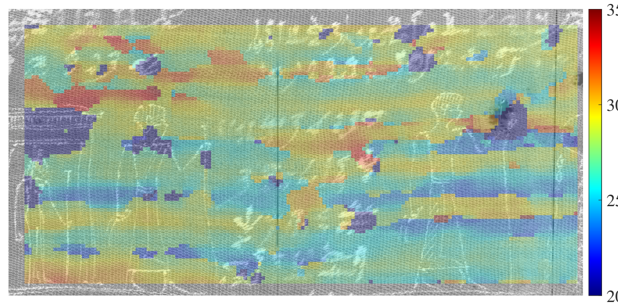


Fig. 8: Horizontal thread counting with the proposed algorithm for sample 1.

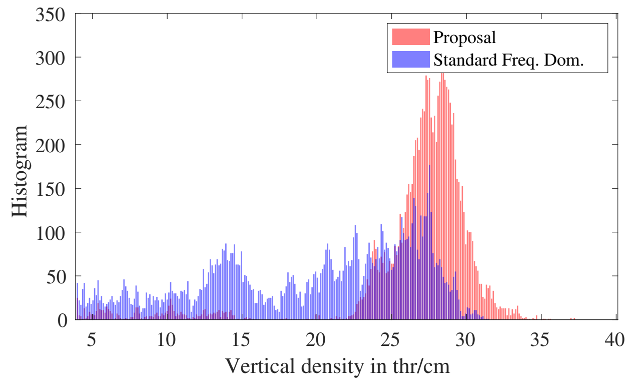


Fig. 9: Histogram for horizontal densities for sample 1 using the standard 2D-DFT and the proposed approach.

from samples as in Fig. 4.a. The proposed approach fails in some areas, e.g., in the middle area to the left where a dark blue area can be found. In this area, the algorithm focuses on the drawing on top of the fabric, with horizontal lines. Note that dark blue, 20, denotes a value of 20 or lower.

B. Ancient Egyptian textile sample 2

By applying the proposed approach to the ancient Egyptian textile sample 2 we draw similar conclusions. However, in this case, the high-density value corresponds

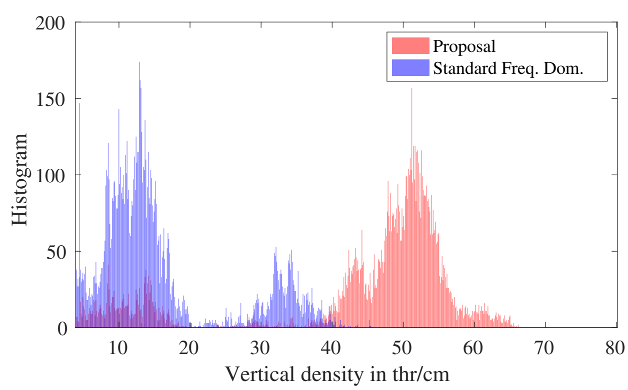
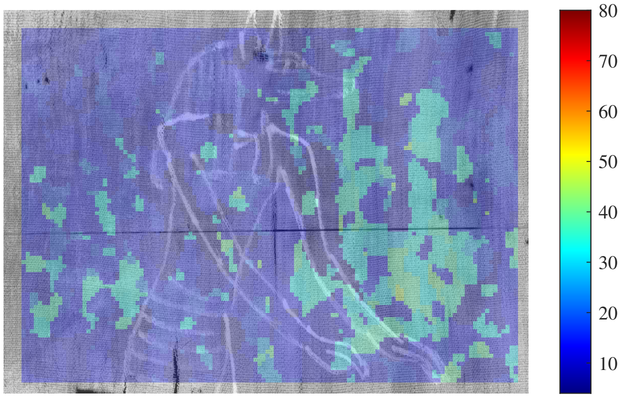
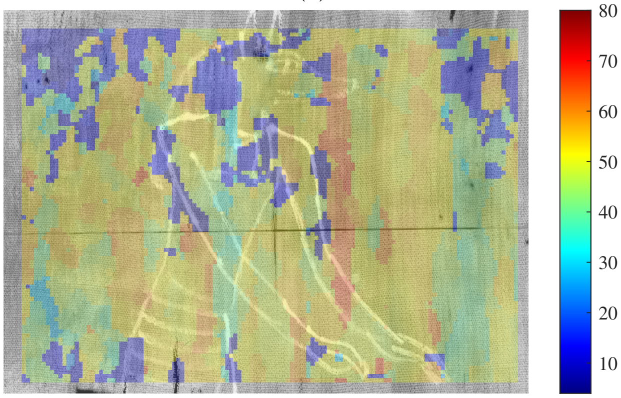


Fig. 10: Histogram for vertical densities for sample 2 using the standard 2D-DFT and the proposed approach.



(a)



(b)

Fig. 11: Vertical thread counting for sample 2 using (a) the standard 2D-DFT approach and (b) the new approach proposed.

to the vertical threads. In Fig. 10 we depict the histograms for both the standard 2D-DFT method and the new proposed one. Since the maximum value is quite high, the standard approach cannot provide a good estimation throughout the fabric. Furthermore, most of the estimations concentrate around 13 when they should be above 50. In Fig. 11 it is observed that while the standard approach in (a) is useless the proposed method in (b) is providing results consistent with the analysis of the PSD and the sample.

VI. Conclusions

When starting to process ancient Egyptian textiles we selected 3 samples, the ones described and sample 3 (1984/79/IX/4: ca. 332-300 BC Greco-Roman Period). While the standard 2D-DFT worked for sample 3, it did not for the other two. After an insightful study, we concluded that for these textiles the 2D-DFT along one axis exhibited remarkably low values for the corresponding maximum, while some maxima were found due to some diagonal patterns observed in the fabric. The new method developed here exploits these discoveries to provide an accurate estimate of the thread densities. Future work will be needed to extend the study to a larger number of samples, refining the approach and/or its parameters.

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